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The impact of flood control on the loss of wetlands in Argentina

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ABSTRACT

1. Wetlands are among the most important ecosystems on Earth, but historically they have been degraded and destroyed by humans. The south east of Córdoba province in central Argentina was covered by hundreds of wetlands in a vast matrix of grasslands and savannas. In the last few centuries, this area has been mostly transformed into agriculture, forcing wetlands to become the last refuge for remaining wildlife.
2. Since the mid-1970s, a gradual increase in rainfall has enlarged the area occupied by wetlands. To reverse the situation, vast flooded regions were altered by the construction of artificial drainage channels, including important areas for conservation of biodiversity.
3. A non-supervised classification of satellite images was used to assess the changes in flooded areas of south-eastern Córdoba before the main floods (1987–1988) and after channelizations occurred (2007). Areas with high channelization (Córdoba) and non-channelization (Santa Fe) were compared for years with the same amount of accumulated rainfall.
4. The pluviometric registers in both regions showed a trend of increasing annual rainfall, and this was reflected in a 65.9% increase (64 837 ha) of the flooded area in Santa Fe. Conversely, the channelized area in Córdoba suffered a loss of 12% of its ponds, corresponding to a 14.7% reduction of the flooded area (11 655 ha). A greater reduction in the flooded area (42.1%) was observed when considering only the western portion of the Córdoba site where most of the channelization occurred.
5. These results indicate that besides the mitigation of floods, the channelization in Córdoba favoured agriculture expansion at the expense of wetlands, thereby destroying these wildlife refuges. Wetlands are important for their biodiversity, ecosystem services, and cultural legacy. In central Argentina the channelization process still continues, so it is of the utmost importance to support conservation actions leading to sustainable management and territorial planning of this region.

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INTRODUCTION

Wetlands are among the most important ecosystems on Earth and they have important functions and values already recognized in conservation programmes at a continental scale (Mitsch and Gosselink, 2000). These sites of great complexity are, at the same time, of enormous environmental importance because of the ecosystem functions that they support and the natural value that they

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represent (Carletti *et al.*, 2004). They not only play a significant role in basin development, water purification, climate change mitigation, flood control, and replenishment of aquifers, but also possess a high cultural value. Moreover, wetlands support a unique biological diversity characterized by a high level of endemism of animals and plants (Mitsch and Gosselink, 2000; Ramsar, 2005; Baker *et al.*, 2006), and provide a refuge for protection, resting, feeding, and mating for several birds, mammals, and other vertebrates, some of which are seriously threatened with extinction (Mitsch and Gosselink, 2000).

Despite their undeniable importance, wetlands have been the target of indiscriminate degradation and destruction caused by human activities (Neiff, 1997; Canevari *et al.*, 1998; Carletti *et al.*, 2004). The history of wetland management was driven by the misconception that wetlands were lands that should either be avoided or drained and filled. Therefore, wetland alteration or destruction is, in a sense, an extreme form of wetland management (Mitsch and Gosselink, 2000). These environments are under great pressure from human disturbance, both locally and globally (Brönmark and Hansson, 2002; Saunders *et al.*, 2002). O'Connell (2003), for example, estimated that more than 50% of the world's wetlands have been altered, degraded, or lost in the last 150 years. Agriculture and other land uses related to population growth, overexploitation of natural resources, and technological development have caused this loss and/or degradation of different wetland types and their species and ecosystem services to continue, and it may exceed that of many other ecosystems (Finlayson, 2012). Added to this, global climate change may alter the hydrological parameters of wetlands and affect the species that depend on them (Hartig *et al.*, 2002).

The true extent and loss of wetlands remain unclear owing to their complexity and natural variations (Maltby and Acreman, 2011). The loss and degradation of inland wetlands have been documented in many parts of the world, but there are only a few reliable estimates (Millennium Ecosystem Assessment, 2005). An exact mapping of wetlands is a useful tool to understand the functions of wetlands and to monitor their responses to natural and anthropogenic changes (Baker *et al.*, 2006). Techniques to fill these gaps in the baseline inventory are needed to assess and monitor wetland changes both temporally and spatially (Davidson and Finlayson, 2007).

In the province of Córdoba, Argentina, there are more than 2 million hectares of lowlands and flooded areas related to watercourses (Dulce, Segundo, Cuarto and Quinto rivers), whose major extensions are in the southern and south-eastern sections of the province (Mengui, 2000). Saladillo wetlands, located in this region, are one of the biodiversity hotspots of the province, and were declared an Important Bird Area in 2005 by Birdlife International (Di Giacomo, 2005). These wetlands constitute the discharge area of all drainage systems in southern Córdoba, and they originally involved a complex network of ponds interconnected by shallow marshes (Blarasin *et al.*, 2005a). However, this region also represents the most productive area for agriculture and ranching in the whole province; both activities identified as main causes of soil degradation and the replacement of natural environments (Bertonatti and Corcuera, 2000; Cabido *et al.*, 2003). Therefore, besides being a refuge for wildlife, the wetlands of south-eastern Córdoba are also associated with the last remnants of natural grasslands and savannas of the province, which are among the most endangered ecoregions of Argentina (Bertonatti and Corcuera, 2000).

Since the mid-1970s, the region has shown a marked trend of increasing rainfall, resulting in augmented surface runoff and groundwater level, which has led to an increase in the flooded area (Blarasin *et al.*, 2005a; Cabrera *et al.*, 2007). This phenomenon created social and economic problems in the region, such as damaging and creating difficulties in communication and loss of agricultural and livestock lands (Cuello *et al.*, 2003; Giai, 2004). These problems coincided with a period in which Argentina approved the commercial release of transgenic soybeans, together with strong technology adoption and deep social transformations that changed the production profile of the country (Pengue, 2004). This contraposition between floods and production encouraged the local government to develop engineering solutions to reverse the floods. From 2000, the provincial government of Córdoba started the construction of artificial drainage channels in the south east, which was followed by numerous illegal channels built by private owners (Cuello *et al.*, 2003). These hydraulic works, which started with the aim of solving the flooding problems, resulted in reduction of the flooded area and its function as a hydrological regulator as well as the loss of the endorheic status of its basins (Blarasin *et al.*, 2005a). However, the magnitude of wetland loss was never evaluated and the current status of these important biodiversity areas is unknown, while the illegal process of channelization by landowners still continues with the justification of solving the flooding problems.

The main aim of this work was to evaluate changes in the surface area covered by wetlands in the south east of Córdoba province, using satellite images from before the largest floods and channelization processes occurred (1987–1988) as well as images acquired after the main channelization infrastructure was developed (2007). Two areas in this region with different levels of channelization were compared, including another site in the south east of the study area (in southern Santa Fe province and northern Buenos Aires) where no channels were constructed. The rainfall registers of this region were monitored also to contrast the effects caused by natural factors (rainfall) and anthropogenic factors (channelization).

METHODS

Study area

The study area comprised the south east of Córdoba, the south of Santa Fe and the north of Buenos Aires provinces, all of which feature several wetlands as part of their landscape (Figure 1). The analysis was concentrated in two areas of 1 960 590 ha. One of these was located in the south east of Córdoba province (site A), in the south section of the quadrant 228/83 generated by the satellite Landsat 5 (left superior corner 32°50′- 63°58′; right inferior corner S33°54′- W62°12′). The second site (B) was located 150 km south east from the first site, in the south of Santa Fe province, occupying the north sector of the quadrant 227/84 from the same satellite (left superior corner S33º52′- W62º50′; right inferior corner S34º47′- W60º51′).

The relief of this region is formed by plains and undulating plains. The climate is sub-humid and precipitation averages 700–800 mm year^{-1}. Aquatic environments from the study area can be grouped into four classes on the basis of their origin. The first class comprises ponds of aeolian origin associated with different types of dunes, which are elongated and egg-shaped in a NNE–SSW direction, closely associated with phreatic level. The second class consists of ponds associated with deflation hollows, which are rounded or slightly egg-shaped, generally temporary and fed by rainwater or phreatic flow. The third are ponds of mixed (aeolian and tectonic) origin, which are rounded or sub-rounded without defined limits, fed by phreatic flow. The fourth are

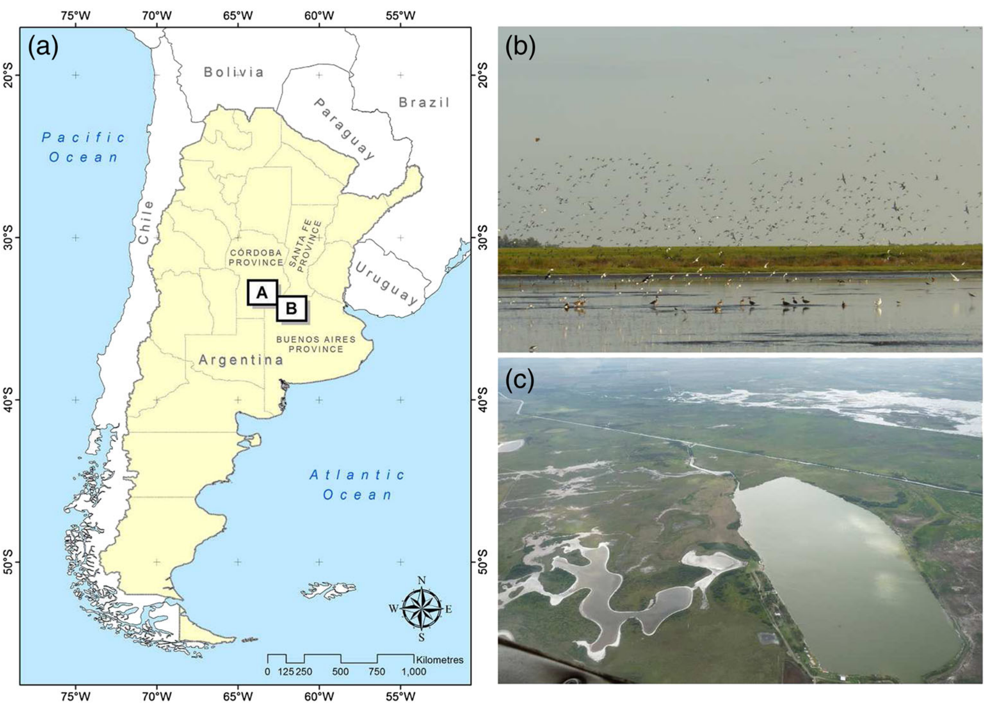

Figure 1. (a) Location of the study area in the centre of Argentina. Site A is located in the south east of Córdoba province and Site B is in the south of Santa Fe and the north of Buenos Aires provinces; (b) a representation of the richness of birds present in these wetlands; and (c) an aerial view of Saladillo wetlands as an example of the type of wetlands in the region.

ponds originating from rivers, that are half-moon shaped, sub-rounded or irregular, associated with many meanders, palaeo-bed rivers or palaeo-floodplains connected to rivers (Cantú and Degiovanni, 1987). Most of the shallow areas of the wetlands are covered by typical marsh vegetation of the pampas, dominated by *Typha* spp., and floating vegetation as *Lemna* spp. and *Pistia* spp. The dominant vegetation surrounding the wetlands are grasslands of *Festuca* spp. and *Spartina* spp., but in the lowlands the grasslands are dominated by salt-tolerant species such as *Distichlis* spp. (Miatello and Casañas, 2005).

This region is one of the most productive areas for agriculture in Córdoba, although the low-lying areas are used for cattle ranching and pastures. In spite of the high human activity in the region, there are still noteworthy places for typical and charismatic species in these wetlands of central Argentina, providing protection and places for rest, feeding, and breeding of many birds, mammals, and other vertebrates, many of them considered to be threatened species (Mengui, 2000). Particularly important are the migratory or threatened aquatic birds, such as Chilean flamingo (*Phoenicopterus chilensis* Molina), Andean flamingo (*Phoenicoparrus andinus* Philippi) (Brandolin and Ávalos, 2010), buff-breasted sandpiper (*Tryngites subruficollis* Vieillot), Hudsonian godwit (*Limosa haemastica* Linnaeus) and black-necked swan (*Cygnus melancoryphus* Molina) (Miatello and Casañas, 2005; Brandolin *et al*., 2011). The region is the centre of the main corridors for movement of continental migratory birds, especially those coming from North America and those coming from southern Argentina (Di Giacomo, 2005). The south east of Córdoba has two sites declared to be Important Bird Areas (IBA) by BirdLife International because they have a significant representation of all the aquatic bird species of this region (BirdLife International, 2012). Unfortunately, despite being considered of great importance for conservation, these two sites do not have any effective legal protection.

Image analysis

Four Landsat TM satellite images were selected, two of them from the study site A in Córdoba obtained in June 1987 and July 2007, and the other two from the study site B in Santa Fe obtained in September 1988 and May 2007. July is the driest month in this region and January the wettest. Given the seasonality of the region, long-term monthly precipitation data were acquired from the RIOCUARTO_AERO and LABOULAYE_AERO meteorological stations from the KNMI climate explorer (http://climexp.knmi.nl/). These weather stations are the closest available to the study area. To overcome the problem of seasonality and ensure that the images were comparable, only those images that had the same amount of rain accumulated in the 12 months preceding the date of image collection were selected (i.e. 883 and 885 mm for 1987 and 2007, respectively, in Córdoba [http://climexp.knmi.nl/data/pa87453.dat]; 870 and 822 mm for 1988 and 2007 in Santa Fe [http://climexp.knmi.nl/data/pa87534.dat]). Rainfall data and a bibliographic review were used to confirm that the rainfall increased in the last few years at the study sites as for the entire region (Blarasin *et al*., 2005a; Cabrera *et al*., 2007).

ENVI 4.2 was used to co-register the four images using a previous geo-registered image from March 2000 as a base image (http://glcf.umiacs.umd.edu). To determine the areas covered by water in each image, a specific method based on a non-supervised classification was devised. All the images were displayed in the false negative colour composition of the satellite bands (7-5-2 RGB) in ArcGIS 9.1 (ESRI, 2004), and the ArcMap Natural Breaks tool (Jenks' Natural Breaks algorithm) was used to classify the values of each pixel of the images in nine different classes. Natural Breaks classes are based on natural groupings inherent in the data. Class breaks group similar values and maximize the differences between classes (ESRI, 2010). From the nine classes created by this tool for the negative colour composition of Landsat images, the first class was designated as water and the other eight classes as no-water. The results of these classifications were validated through ground truthing by visiting different regions of the study area, and by comparing the distribution and shape of the ponds with high resolution images available through Google Earth (http://earth.google.com/) from the closest date in 2007 for each site (Izquierdo *et al*., 2008). Exactly the same classification procedure was followed with the four images to ensure their comparability.

The images from the south-east province of Córdoba (site A) were divided into two blocks that have undergone different histories of water management. This division coincides with what is known as the tectonic fault of Viamonte (Kraus *et al*., 1999). The portion to the west has suffered a high channelization process while only minimal intervention of this type of hydraulic work has occurred in the eastern part. Also, enlargement of the Saladillo wetlands was performed to analyse the changes in that region, which is considered the second site of importance for biodiversity in the province (Di Giacomo, 2005).

The classifications generated for each date and site were filtered by selecting polygons (henceforth ‘ponds’) representing flooded areas with more than 5 ha of superficial water. For each site the following metrics were calculated: number of ponds, total flooded surface area, and area of the largest pond (which is not necessarily the same for each time-frame that was analysed).

To analyse the fate of the drained areas between 1987/1988 and 2007, 100 points were randomly distributed over these areas. Each point was then projected over Google Earth high resolution images, considering only images with acquisition dates between 2008 and 2012. According to the land cover observed (using the most recent high resolution image available for each point), all the points were categorized into three different land-cover categories: wetland; grassland or other vegetation; and agriculture.

RESULTS

The historical series of rainfall data for different locations along the whole region showed an increase in the annual average in recent years (Table 1). These averages in some cases were 100 mm above the historical ones. The same pattern was observed for the south east of Córdoba, south of Santa Fe and north of Buenos Aires provinces (Figure 2).

This increase in rainfall was not reflected in an enlargement of the flooded area in the whole region. The Córdoba region (Figure 3(A) and (B)) suffered a significant decrease in the three variables analysed, a reduction of the total flooded area being the most evident. In 1987, 2248 ponds were identified but only 1978 were detected in 2007, along with a shrinkage >10 000 ha of wetlands (Table 2). In addition, when analysing separately

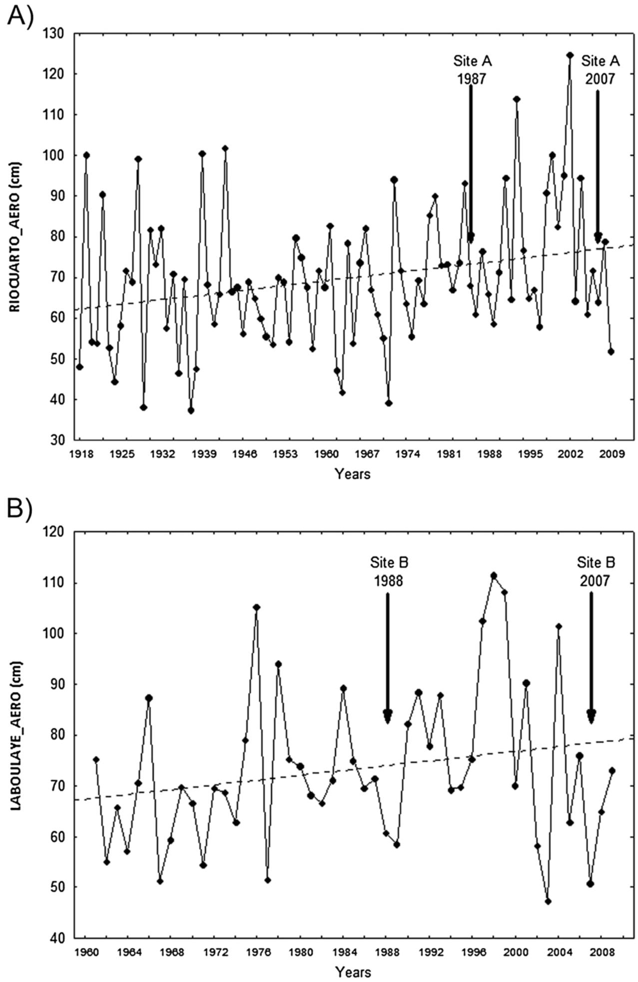

Figure 2. Evolution of the annual rainfall in (A) the south east of Córdoba province and (B) the south of Santa Fe province (RIOCUARTO_AERO and LABOULAYE_AERO, meteorological stations, the nearest to each site, respectively). The dotted line shows the observed trend. The arrows show the year of acquisition of images for each site.

Table 1. Summary of historical rainfall data from previous studies. The increases in annual averages are highlighted

Town	Location	Period	Observations	Source
Laboulaye, Cba.	34°07′S 63°23′W	1903–1998	Increase in the annual average rainfall from 700 to 1000 mm	Carballo *et al.* 2000
Cnel. Moldes, Cba.	33°37′S 64°35′W	1896–2003	Last 7 years with annual rainfall Average 258 mm above the average of the series (1088 mm)	Blarasin *et al.* 2005b
San Basilio, Cba	33°29′S 64°18′W	1945–2005	Dry cycle until 1971 with 629 mm Average and wet cycle up to the present with an average rainfall of 946 mm	Cabrera *et al.* 2007
Oliveros, Santa Fe	32°33′S 60°51′W	1970–2007	132 mm increase in the average in the last 7 years	Estación Experimental Agropecuaria Oliveros, INTA, Santa Fe

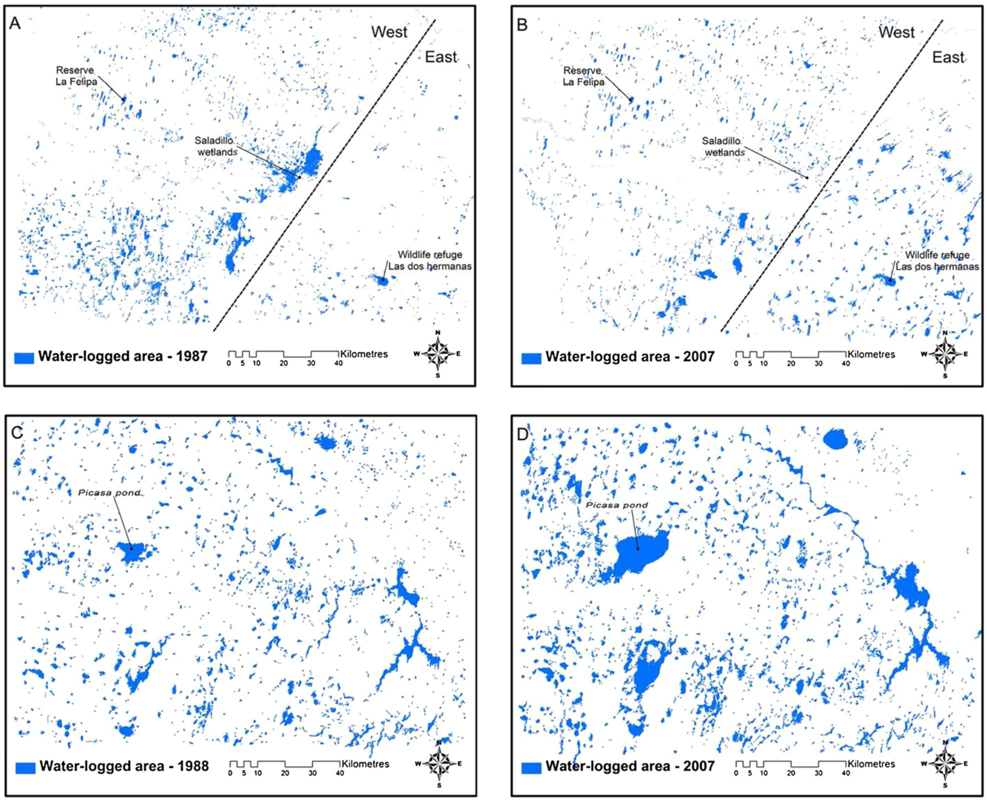

Figure 3. Water bodies >5 ha observed in the south east of Córdoba province in 1987 (A) and 2007 (B), and in the south of Santa Fe province and north of Buenos Aires province in 1988 (C) and 2007 (D). The dotted line indicates the east block (low channelization) and west block (high channelization) in the Córdoba study site.

Table 2. Changes observed in the wetlands of the south east of Córdoba province (site A – channelized area) and in the south of Santa Fe province (site B – non-channelized area) between 1987/1988 (before channelization) and 2007 (after channelization). At site A, two different blocks are also described in more detail: the east block (low channelization) and west block (high channelization). (–) represents a decrease and (+) an increase for each metric

	Waterlogged area			Number of ponds			Size of largest patch		
Site	Before (ha)	After (ha)	Change (%)	Before (ha)	After (ha)	Change (%)	Before (ha)	After (ha)	Change (%)
Site A	79 263	67 608	– 14.7	2248	1978	– 12.0	3638	1684	– 53.7
West	70 200	40 597	– 42.1	1932	1408	– 27.1			
East	9135	27 537	+ 201.0	317	576	+ 81.7			
Site B	98 285	163 122	+ 65.9	1909	2341	+ 22.6	5263	20 854	+ 218.0

the two blocks with different management histories in site A, the block with high channelization (western) showed a decrease of 27.1% in the number of ponds and a reduction >40% in the flooded area (Figure 3(A) and (B)). Conversely, in the eastern portion where less channelization occurred, the opposite pattern was observed with more than twice the surface area being covered by water in 2007 (Table 2).

In the western block, the region corresponding to the Saladillo wetlands presented the most noticeable change, with a 69% decrease in the surface area and a 19.6% reduction in the number of ponds (Figure 4). The decrease in Saladillo wetlands corresponds to the greatest reduction of the largest patch in this region, from 3638 ha in 1987 to only 269 ha in 2007 (Table 2).

Within site B, in the Santa Fe province, more than 400 new ponds were recorded in 2007, with a 65.9% increase in the flooded area. This expansion of the wetlands surface was partly due to the new ponds, but mainly to the expansion of La Picasa pond by 218.9% in the last 19 years (from 5029 ha in 1988 to 20 854 ha in 2007). The Laguna de Gómez, with an area of 6539 ha, was the largest pond in this sector in 1987, while in 2007 Laguna La Picasa became the largest one (Figure 3(C) and (D)).

The random points distributed along the drained areas demonstrated that almost half (48%) of these areas were transformed to agriculture: 36% of the

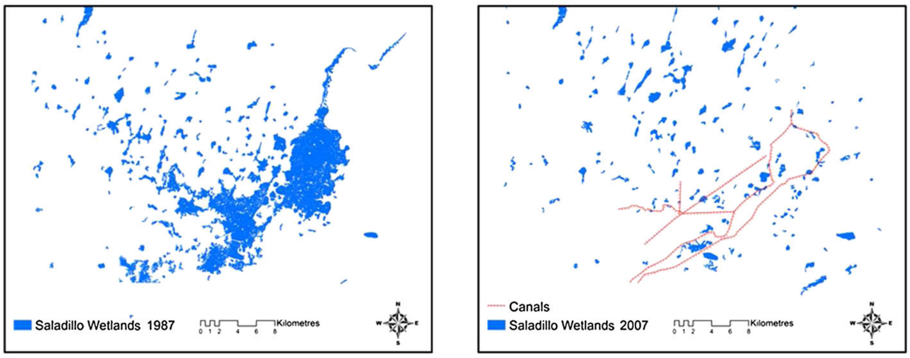

Figure 4. Saladillo wetlands in 1987 (left) and 2007 (right). The 2007 image shows the main channels constructed for drainage of the region.

points occurred in areas now covered by grasslands or other vegetation, which usually represents the intermediate state before transformation to agriculture. Only 16% of the points were observed in areas re-established with wetlands.

DISCUSSION

The present study shows a rapid and important loss of wetlands in the south east of Córdoba province (~40% lost in 20 years) when compared with global estimations in which 50% of wetlands have been altered, degraded or lost in 150 years (O'Connell, 2003; Finlayson, 2012). The high levels of channelization in the south east of Córdoba reduced the potentially adverse effects of flooding caused by the increase in rainfall. However, these human activities also greatly reduced the number and the extent of the natural wetlands in this region, many of them of great importance for biodiversity conservation.

At a regional scale, the south east of Córdoba province and its associated wetlands constitute an area of hydrological discharge. In the past, these wetlands were the predominant landscape of the region. The tendency of rainfall to increase (observed since the mid-1970s) has produced an augmentation of surface water and a higher water table with a consequent increase in the flooded area (Blarasin *et al.*, 2005a; Cabrera *et al.*, 2007). This can be observed in the region of Santa Fe province and the eastern block of the Córdoba site, in contrast with the pattern observed in the western portion, making evident the effect of human-induced activities on flooding. As channels were built to reduce the impact of floods, the expected result was that the wetland surface would either not change or increase slightly (considering the rainfall trend) in the channelized area. However, more than 30 000 ha of wetlands (>500 ponds) were lost and most of these areas were transformed or are in the process of being transformed to agriculture. This translates into a net loss of 10 000 ha in the entire area analysed in Córdoba and demonstrates that, besides flood control, channelization was used as a mechanism for advancing the agricultural frontier in central Argentina. As a result, vast flooded areas were lost along with the biodiversity that they supported.

Because several organisms are dependent on wetlands and their surroundings, the loss of their quality brings about a reduction in species abundance and richness, especially of waterbirds (Newton, 1998). This diminution in diversity is due to several factors (not mutually exclusive) such as habitat fragmentation, changes in hydrological regimes, loss of connectivity, restricted movement between populations, loss of spatial heterogeneity, increased mortality and loss of resting habitat, among others (Findlay and Bourdages, 2000; Amezaga *et al.*, 2002; Niemuth and Solberg, 2003; Faulkner, 2004). Maintaining the quality and quantity of aquatic habitats ensures the continuity of certain species adapted to these particular environments (Blanco, 1998).

The Saladillo wetlands suffered a large decrease in both total flooded area and size of the largest patch (Figures 4 and 5). Channelization projects have been conducted in this area since 2002, leading to an almost entire loss of one of the most important sites of biodiversity in the province (Di Giacomo, 2005). The channels also had an adverse impact on the aquatic systems of the region by increasing the speed of runoff and reducing the base-flows generating backward erosion (S. Degiovanni, pers.comm.). Small, private, unauthorized channelizations are also common in this region, not only causing a loss of

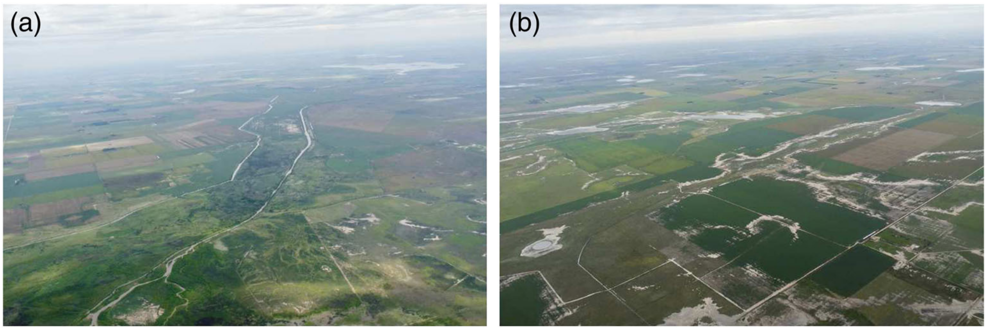

Figure 5. Aerial photographs of different sectors of the Saladillo wetlands after their channelization: (a) two of the main channels constructed in this area; (b) areas formerly occupied by wetlands and now transformed to agriculture, which surrounds the small remaining number of ponds.

wetlands and biodiversity but also transforming endorheic (e.g. Chucul stream and Grandes Lagunas system) into exorheic basins.

The degradation and loss of wetlands have taken place more rapidly than those experienced by other ecosystems (Millennium Ecosystem Assessment, 2005). Usually, the hydrological modification of wetlands occurs for some purpose not directly related to the wetlands themselves; wetland destruction is an inadvertent result (Mitsch and Gosselink, 2000). Channelization of the south east of Córdoba was developed for flood control, but to carry flood waters away involved the destruction of important sites for conservation (e.g. Saladillo wetlands) and helped the expansion of intensive human activities in the dried areas (Figures 4 and 5). As this present work shows, the decline of wetlands in this region is caused neither by natural processes nor by periods of drought, but by human factors. In this region, as well as around the world, the major cause of wetland loss is the conversion of wetlands to agriculture (Mitsch and Gosselink, 2000).

Although since 1991 Argentina is a contracting party to the Convention on Wetlands of International Importance, (the Ramsar Convention), the wetlands of south-eastern Córdoba do not have any specific legal protection. This area has only two small nature reserves (Reserva Provincial 'Laguna La Felipa' and Refugio de Vida Silvestre 'Las Dos Hermanas', 2362 ha in total; Figure 3). The lack of policies on protected areas has had an adverse impact on wetlands, allowing the channelization process without any control. The water legislation (Law Nº5589/73) and the environmental law (Law Nº 7343/85) of Córdoba province requires the preparation of environmental impact assessments for any public or private works that may change the condition of wetlands. However, the existence of these laws was not enough to prevent drainage of the wetlands in the south east of the province. As Finlayson (2012) recognized in his review, the continuous degradation of wetlands among an increasing number of wetland policies and actions, emphasizes the need for an analysis of the effectiveness of these actions, or rather, a verification of the effectiveness of their application.

However, it is possible to find good examples where wetlands and human development have found a balance based on wetland restoration and sustainable development. In the Everglades of South Florida (USA), a large number of dams, canals and systems of locks that altered the natural functioning of wetlands were constructed in the early 20th century to provide flood protection and to extract water for a growing human population. Nevertheless, in 2000 the Comprehensive Everglades Restoration Plan was implemented, encouraged by the increasing interest in environment and water conservation (Johnson *et al*., 2007). This plan had the aim of restoring the quantity, quality, hydroperiod and water distribution to an original state in the Everglades. At present only 30% of the original Everglades is used for agriculture or urban development, but the rest of the area was restored and is considered a Water Conservation Area (Richardson, 2010). Effectively managed wetlands can provide alternative or complementary habitats for waterbirds and mitigate the adverse effects of wetland loss and degradation (Ma *et al*., 2010). The experience in the Everglades and other similar examples of wetland management where agricultural development is combined with water resources conservation and wetland restoration, can be used to design a management plan for the wetlands of the south east of Córdoba (Schoof, 1980; Elphick and Oring, 1998; Isola *et al*., 2002; Comprehensive Assessment of Water Management in Agriculture, 2007).

In addition to the specific causes affecting the study area, global climate change is recognized as a major threat to the survival of species and the integrity of ecosystems worldwide (Hulme, 2005). Potentially, as a result of far-reaching unintended consequences of global climate change, the loss of permanent wetlands (e.g. Saladillo wetlands) reduces the chances of wildlife finding refuge in prolonged periods of drought (Maltby and Acreman, 2011). For example, a prolonged drought affected the central part of Argentina in the summer of 2011–2012 with high economic losses in agriculture and problems of water supply (Gobierno de la Provincia de Córdoba, 2012). An important management strategy to ensure wetland sustainability is the prevention or reduction of additional stress that would diminish the ability of wetlands to respond to climate change (Erwin, 2009). Water is an irreplaceable resource, and the demands for water as well as the requirements of other wetland ecosystem services (e.g. water for food production) are increasing all over the world as a result of human population growth and economic development (Peteán and Cappato, 2005; Comprehensive Assessment of Water Management in Agriculture, 2007). Eliminating the existing pressures on wetlands and improving their resilience is vitally important to an overall strategy to mitigate the adverse effects of climate change and cyclic climate variations (Millennium Ecosystem Assessment, 2005).

Poorly planned channelization and illegal channels have generated one of the worst environmental disasters in the province of Córdoba. A proper strategy for flood management should be based on the vertical components of water balance, particularly infiltration, evaporation and evapotranspiration (Degioanni *et al*., 2002). It should also be supported by a planned expansion of agriculture and a participatory environmental management that considers the dynamics of ecosystems and the importance of preserving wetlands in the region (Cuello *et al*., 2003). Wetlands should be properly managed because of their vital importance for hydrological balance as well as for being home to a diversity of animal and plant species. No less important is the cultural legacy of these wetlands. A management plan based on scientific research and the consensus of the different parties involved (land owners, local people, government, scientists and conservationists), is critical for the long-term conservation of these wetlands and their biodiversity. However, law enforcement and conservation policies are urgently needed to stop the degradation of these fragile ecosystems and their rapid loss.

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